1.3 Fuel Oil Combustion

1.3.1 General[1-2, 26]

Two major categories of fuel oil are burned by combustion sources: distillate oils and residual oils. These oils are further distinguished by grade numbers, with Nos. 1 and 2 being distillate oils; Nos. 5 and 6 being residual oils; and No. 4 either distillate oil or a mixture of distillate and residual oils. No. 6 fuel oil is sometimes referred to as Bunker C. Distillate oils are more volatile and less viscous than residual oils. They have negligible nitrogen and ash contents and usually contain less than 0.3 percent sulfur (by weight). Distillate oils are used mainly in domestic and small commercial applications. Being more viscous and less volatile than distillate oils, the heavier residual oils (Nos. 5 and 6) must be heated for ease of handling and to facilitate proper atomization. Because residual oils are produced from the residue remaining after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen, and sulfur. Residual oils are used mainly in utility, industrial, and large commercial applications.

1.3.2 Emissions[27]

Emissions from fuel oil combustion depend on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Because the combustion characteristics of distillate and residual oils are different, their combustion can produce significantly different emissions. In general, the baseline emissions of criteria and noncriteria pollutants are those from uncontrolled combustion sources. Uncontrolled sources are those without add-on air pollution control (APC) equipment or other combustion modifications designed for emission control. Baseline emissions for sulfur dioxide (SO_2) and particulate matter (PM) can also be obtained from measurements taken upstream of APC equipment.

In this section, point source emissions of nitrogen oxides (NO_x), SO_2, PM, and carbon monoxide (CO) are being evaluated as criteria pollutants (those emissions for which National Primary and Secondary Ambient Air Quality Standards have been established. Particulate matter emissions are sometimes reported as total suspended particulate (TSP). More recent data generally quantify the portion of inhalable PM that is considered to be less than 10 micrometers in aerodynamic diameter (PM-10). In addition to the criteria pollutants, this section includes point source emissions of some noncriteria pollutants, nitrous oxide (N_2O), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs), as well as data on particle size distribution to support PM-10 emission inventory efforts. Emissions of carbon dioxide (CO_2) are also being considered because of its possible participation in global climatic change and the corresponding interest in including this gas in emission inventories. Most of the carbon in fossil fuels is emitted as CO_2 during combustion. Minor amounts of carbon are emitted as CO, much of which ultimately oxidizes to CO_2 or as carbon in the ash. Finally, fugitive emissions associated with the use of oil at the combustion source are being included in this section.

Tables 1.3-1, 1.3-2, 1.3-3, and 1.3-4 present emission factors for uncontrolled emissions of criteria pollutants from fuel oil combustion. A general discussion of emissions of criteria and noncriteria pollutants from coal combustion is given in the following paragraphs. Tables 1.3-5, 1.3-6, 1.3-7, and 1.3-8 present cumulative size distribution data and size-specific emission factors for

Table 1.3-1 (Metric Units). CRITERIA POLLUTANT EMISSION FACTORS FOR UNCONTROLLED FUEL OIL COMBUSTION

Firing Configuration (SCC)[a]	SO_2[b]		SO_3[c]		NO_x[d]		CO[e,f]		Filterable PM[g,h]	
	kg/10^3 L	EMISSION FACTOR RATING	kg/10^3 L	EMISSION FACTOR RATING	kg/10^3 L	EMISSION FACTOR RATING	kg/10^3 L	EMISSION FACTOR RATING	kg/10^3 L	EMISSION FACTOR RATING
Utility boilers										
No. 6 oil fired, normal firing (1-01-004-01)	19S	A	0.69S	C	8	A	0.6	A	1.12(S)+0.37	A
No. 6 oil fired, tangential firing (1-01-004-04)	19S	A	0.69S	C	5	A	0.6	A	1.12(S)+0.37	A
No. 5 oil fired, normal firing (1-01-004-05)	19S	A	0.69S	C	8	A	0.6	A	1.2	B
No. 5 oil fired, tangential firing (1-01-004-06)	19S	A	0.69S	C	5	A	0.6	A	1.2	B
No. 4 oil fired, normal firing (1-01-005-04)	18S	A	0.69S	C	8	A	0.6	A	0.84	B
No. 4 oil fired, tangential firing (1-01-005-05)	18S	A	0.69S	C	5	A	0.6	A	0.84	B
Industrial boilers										
No. 6 oil fired (1-02-004-01/02/03)	19S	A	0.24S	A	6.6	A	0.6	A	1.12(S)+0.37	A
No. 5 oil fired (1-02-004-04)	19S	A	0.24S	A	6.6	A	0.6	A	1.2	B
Distillate oil fired (1-02-005-01/02/03)	17S	A	0.24S	A	2.4	A	0.6	A	0.24	A
No. 4 oil fired (1-02-005-04)	18S	A	0.24S	A	2.4	A	0.6	A	0.84	B
Commercial/institutional/residential combustors										
No. 6 oil fired (1-03-004-01/02/03)	19S	A	0.24S	A	6.6	A	0.6	A	1.12(S)+0.37	A
No. 5 oil fired (1-03-004-04)	19S	A	0.24S	A	6.6	A	0.6	A	1.2	B
Distillate oil fired (1-03-005-01/02/03)	17S	A	0.24S	A	2.4	A	0.6	A	0.24	A
No. 4 oil fired (1-03-005-04)	18S	A	0.24S	A	2.4	A	0.6	A	0.84	B
Residential furnace (A2104004/A2104011)	17S	A	0.24S	A	2.2	A	0.6	A	0.3	A

Table 1.3-1 (cont.).

[a] SCC = Source Classification Code.

[b] References 1-6,23,42-46. S indicates that the weight % of sulfur in the oil should be multiplied by the value given. For example, if the fuel is 1.0% sulfur, then S = 1.0.

[c] References 1-5,45-46,22.

[d] References 3-4,10,15,24,42-46,48-49. Expressed as NO_2. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO. For utility vertical fired boilers use 12.6 kg/10^3 L at full load andnormal (>15%) excess air. Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are related to fuel nitrogen content, estimated by the following empirical relationship: kg NO_2 /10^3 L = 2.465 + 12.526(N), where N is the weight percent of nitrogen in the oil. For example, if the fuel is 1.0% Nitrogen, then N equals 1.0.

[e] References 3-5,8-10,23,42-46,48. CO emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.

[f] Emission factors for CO_2 from oil combustion should be calculated using kg CO_2/10^3 L oil = 31.0 C (distillate) or 34.6 C (residual). C equals the weight percent carbon in the fuel. For example, if the fuel is 86% carbon, then C equals 86.

[g] References 3-5,7,21,23-24,42-46,47,49. Filterable PM is that particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values include the sum of that particulate collected on the PM-10 filter of an EPA Method 201 or 201A sampling train and condensable emissions as measured by EPA Method 202.

[h] Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content: where S is the weight % of sulfur in oil. For example, if the fuel is 1.0% sulfur, then S = 1.0.

Table 1.3-2 (English Units). CRITERIA POLLUTANT EMISSION FACTORS FOR UNCONTROLLED FUEL OIL COMBUSTION

Firing Configuration (SCC)[a]	SO_2[b]		SO_3[c]		NO_x[d]		CO[e,f]		Filterable PM[g,h]	
	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING
Utility boilers										
No. 6 oil fired, normal firing (1-01-004-01)	157S	A	5.7S	C	67	A	5	A	9.19(S)+3.22	A
No. 6 oil fired, tangential firing (1-01-004-04)	157S	A	5.7S	C	42	A	5	A	9.19(S)+3.22	A
No. 5 oil fired, normal firing (1-01-004-05)	157S	A	5.7S	C	67	A	5	A	10	B
No. 5 oil fired, tangential firing (1-01-004-06)	157S	A	5.7S	C	42	A	5	A	10	B
No. 4 oil fired, normal firing (1-01-005-04)	150S	A	5.7S	C	67	A	5	A	7	B
No. 4 oil fired, tangential firing (1-01-005-05)	150S	A	5.7S	C	42	A	5	A	7	B
Industrial boilers										
No. 6 oil fired (1-02-004-01/02/03)	157S	A	2S	A	55	A	5	A	9.19(S)+3.22	A
No. 5 oil fired (1-02-004-04)	157S	A	2S	A	55	A	5	A	10	B
Distillate oil fired (1-02-005-01/02/03)	142S	A	2S	A	20	A	5	A	2	A
No. 4 oil fired (1-02-005-04)	150S	A	2S	A	20	A	5	A	7	B
Commercial/institutional/residential combustors										
No. 6 oil fired (1-03-004-01/02/03)	157S	A	2S	A	55	A	5	A	9.19(S)+3.22	A
No. 5 oil fired (1-03-004-04)	157S	A	2S	A	55	A	5	A	10	B
Distillate oil fired (1-03-005-01/02/03)	142S	A	2S	A	20	A	5	A	2	A
No. 4 oil fired (1-03-005-04)	150S	A	2S	A	20	A	5	A	7	B
Residential furnace (A2104004/A2104011)	142S	A	2S	A	18	A	5	A	3	A

Table 1.3-2 (cont.).

[a] SCC = Source Classification Code.

[b] References 1-6,23,42-46. S indicates that the weight % of sulfur in the oil should be multiplied by the value given. For example, if the fuel is 1.0% sulfur, then S equals 1.0.

[c] References 1-5,45-46,22.

[d] References 3-4,10,15,24,42-46,48-49. Expressed as NO_2. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO. For utility vertical fired boilers use 105 lb/10^3 gal at full load and normal (>15%) excess air. Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are related to fuel nitrogen content, estimated by the following empirical relationship: lb NO_2 /10^3 gal = 20.54 + 104.39(N), where N is the weight percent of nitrogen in the oil. For example, if the fuel is 1.0% Nitrogen, then N equals 1.0.

[e] References 3-5,8-10,23,42-46,48. CO emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.

[f] Emission factors for CO_2 from oil combustion should be calculated using lb CO_2/10^3 gal oil = 259 C (distillate) or 288 C (residual). C equals the weight percent carbon in the fuel. For example, if the fuel is 86% carbon, then C equals 86.

[g] References 3-5,7,21,23-24,42-46,47,49. Filterable PM is that particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values include the sum of that particulate collected on the PM-10 filter of an EPA Method 201 or 201A sampling train and condensable emissions as measured by EPA Method 202.

[h] Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content: where S is the weight % of sulfur in oil. For example, if the fuel is 1.0% sulfur, then S equals 1.0.

Table 1.3-3 (Metric Units). EMISSION FACTORS FOR TOTAL ORGANIC COMPOUNDS (TOC), METHANE, AND NONMETHANE TOC (NMTOC) FROM UNCONTROLLED FUEL OIL COMBUSTION

Firing Configuration (SCC)[a]	TOC[b]		Methane[b]		NMTOC[b]	
	$kg/10^3$ L	EMISSION FACTOR RATING	$kg/10^3$ L	EMISSION FACTOR RATING	$kg/10^3$ L	EMISSION FACTOR RATING
Utility boilers						
No. 6 oil fired, normal firing (1-01-004-01)	0.125	A	0.034	A	0.091	A
No. 6 oil fired, tangential firing (1-01-004-04)	0.125	A	0.034	A	0.091	A
No. 5 oil fired, normal firing (1-01-004-05)	0.125	A	0.034	A	0.091	A
No. 5 oil fired, tangential firing (1-01-004-06)	0.125	A	0.034	A	0.091	A
No. 4 oil fired, normal firing (1-01-005-04)	0.125	A	0.034	A	0.091	A
No. 4 oil fired, tangential firing (1-01-005-05)	0.125	A	0.034	A	0.091	A
Industrial boilers						
No. 6 oil fired (1-02-004-01/02/03)	0.154	A	0.12	A	0.034	A
No. 5 oil fired (1-02-004-04)	0.154	A	0.12	A	0.034	A
Distillate oil fired (1-02-005-01/02/03)	0.030	A	0.006	A	0.024	A
No. 4 oil fired (1-02-005-04)	0.030	A	0.006	A	0.024	A
Commercial/institutional/ residential combustors						
No. 6 oil fired (1-03-004-01/02/03)	0.193	A	0.057	A	0.136	A
No. 5 oil fired (1-03-004-04)	0.193	A	0.057	A	0.136	A
Distillate oil fired (1-03-005-01/02/03)	0.067	A	0.026	A	0.041	A
No. 4 oil fired (1-03-005-04)	0.067	A	0.026	A	0.041	A
Residential furnace (No SCC)	0.299	A	0.214	A	0.085	A

[a] SCC = Source Classification Code.

[b] References 16-19. Volatile organic compound emissions can increase by several orders of magnitude if the boiler is improperly operated or is not well maintained.

Table 1.3-4 (English Units). EMISSION FACTORS FOR TOTAL ORGANIC COMPOUNDS (TOC), METHANE, AND NONMETHANE TOC (NMTOC) FROM UNCONTROLLED FUEL OIL COMBUSTION

Firing Configuration (SCC)[a]	TOC[b]		Methane[b]		NMTOC[b]	
	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING	lb/10^3 gal	EMISSION FACTOR RATING
Utility boilers						
No. 6 oil fired, normal firing (1-01-004-01)	1.04	A	0.28	A	0.76	A
No. 6 oil fired, tangential firing (1-01-004-04)	1.04	A	0.28	A	0.76	A
No. 5 oil fired, normal firing (1-01-004-05)	1.04	A	0.28	A	0.76	A
No. 5 oil fired, tangential firing (1-01-004-06)	1.04	A	0.28	A	0.76	A
No. 4 oil fired, normal firing (1-01-005-04)	1.04	A	0.28	A	0.76	A
No. 4 oil fired, tangential firing (1-01-005-05)	1.04	A	0.28	A	0.76	A
Industrial boilers						
No. 6 oil fired (1-02-004-01/02/03)	1.28	A	1.0	A	0.28	A
No. 5 oil fired (1-02-004-04)	1.28	A	1.0	A	0.28	A
Distillate oil fired (1-02-005-01/02/03)	0.252	A	0.052	A	0.2	A
No. 4 oil fired (1-02-005-04)	0.252	A	0.052	A	0.2	A
Commercial/institutional/ residential combustors						
No. 6 oil fired (1-03-004-01/02/03)	1.605	A	0.475	A	1.13	A
No. 5 oil fired (1-03-004-04)	1.605	A	0.475	A	1.13	A
Distillate oil fired (1-03-005-01/02/03)	0.556	A	0.216	A	0.34	A
No. 4 oil fired (1-03-005-04)	0.556	A	0.216	A	0.34	A
Residential furnace (No SCC)	2.493	A	1.78	A	0.713	A

[a] SCC = Source Classification Code.

[b] References 16-19. Volatile organic compound emissions can increase by several orders of magnitude if the boiler is improperly operated or is not well maintained.

Table 1.3-5 (Metric And English Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR UTILITY BOILERS FIRING RESIDUAL OIL[a]

Particle Size[b] (μm)	Cumulative Mass % ≤ Stated Size			Cumulative Emission Factor [kg/10^3 L (lb/10^3 gal)]					
		Controlled		Uncontrolled[c]		ESP Controlled[d]		Scrubber Controlled[e]	
	Uncontrolled	ESP	Scrubber	Factor	RATING	Factor	RATING	Factor	RATING
15	80	75	100	0.80A (6.7A)	C	0.0060A (0.05A)	E	0.06A (0.50A)	D
10	71	63	100	0.71A (5.9A)	C	0.005A (0.042A)	E	0.06A (0.050A)	D
6	58	52	100	0.58A (4.8A)	C	0.0042A (0.035A)	E	0.06A (0.50A)	D
2.5	52	41	97	0.52A (4.3A)	C	0.0033A (0.028A)	E	0.058A (0.48A)	D
1.25	43	31	91	0.43A (3.6A)	C	0.0025A (0.021A)	E	0.055A (0.46A)	D
1.00	39	28	84	0.39A (3.3A)	C	0.0022A (0.018A)	E	0.050A (0.42A)	D
0.625	20	20	64	0.20A (1.74)	C	0.0008A (0.007A)	E	0.038A (0.32A)	D
TOTAL	100	100	100	1A (8.3A)	C	0.008A (0.067A)	E	0.06A (0.50A)	D

[a] Reference 29. Source Classification Codes 1-01-004-01/04/05/06 and 1-01-005-04/05. ESP = electrostatic precipitator.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content where S is the weight % of sulfur in the oil. For example, if the fuel is 1.0% sulfur, then S equals 1.0.
No. 6 oil: A = 1.12(S) + 0.37 kg/10^3 L,
No. 5 oil: A = 1.2 kg/10^3 L
No. 4 oil: A = 0.84 kg/10^3 L

[d] Estimated control efficiency for ESP is 99.2%.

[e] Estimated control efficiency for scrubber is 94%.

Table 1.3-6 (Metric And English Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR INDUSTRIAL BOILERS FIRING RESIDUAL OIL[a]

Particle Size[b] (μm)	Cumulative Mass % ≤ Stated Size		Cumulative Emission Factor[c] [Kg/10^3 l (lb/10^3 gal)]			
			Uncontrolled		Multiple Cyclone Controlled[e]	
	Uncontrolled	Multiple Cyclone Controlled	Factor	RATING	Factor	RATING
15	91	100	0.91A (7.59A)	D	0.20A (1.67A)	E
10	86	95	0.86A (7.17A)	D	0.19A (1.58A)	E
6	77	72	0.77A (6.42A)	D	0.14A (1.17A)	E
2.5	56	22	0.56A (4.67A)	D	0.04A (0.33A)	E
1.25	39	21	0.39A (3.25A)	D	0.04A (0.33A)	E
1.00	36	21	0.36A (3.00A)	D	0.04A (0.33A)	E
0.625	30	—[d]	0.30A (2.50A)	D	—[d]	NA
TOTAL	100	100	1A (8.34A)	D	0.2A (1.67A)	E

[a] Reference 29. Source Classification Codes 1-02-004-01/02/03/04 and 1-02-005-04. NA = not applicable.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content where S is the weight % of sulfur in the oil. For example, if the fuel is 1.0% sulfur, then S equals 1.0.
No. 6 oil: A = 1.12(S) + 0.38 kg/10^3 L,
No. 5 oil: A = 1.2 kg/10^3 L
No. 4 oil: A = 0.84 kg/10^3 L

[d] Insufficient data.

[e] Estimated control efficiency for multiple cyclone is 80%.

Table 1.3-7 (Metric And English Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL BOILERS FIRING DISTILLATE OIL[a]

EMISSION FACTOR RATING: E

Particle Size[b] (μm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor [kg/10^3 L (lb/10^3 gal)]
	Uncontrolled	Uncontrolled
15	68	0.16 (1.33)
10	50	0.12 (1.00)
6	30	0.07 (0.58)
2.5	12	0.03 (0.25)
1.25	9	0.02 (0.17)
1.00	8	0.02 (0.17)
0.625	2	0.005 (0.04)
TOTAL	100	0.24 (2.00)

[a] Reference 29. Source Classification Codes 1-02-005-01/02/03.

[b] Expressed as aerodynamic equivalent diameter.

Table 1.3-8 (Metric And English Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR UNCONTROLLED COMMERCIAL BOILERS BURNING RESIDUAL AND DISTILLATE OIL[a]

EMISSION FACTOR RATING: D

Particle Size[b] (μm)	Cumulative Mass % ≤ Stated Size		Cumulative Emission Factor[c] [kg/10^3 L (lb/10^3 gal)]	
	Uncontrolled, Residual Oil	Uncontrolled, Distillate Oil	Uncontrolled, Residual Oil	Uncontrolled, Distillate Oil
15	78	60	0.78A (6.50A)	0.14 (1.17)
10	62	55	0.62A (5.17A)	0.13 (1.08)
6	44	49	0.44A (3.67A)	0.12 (1.00)
2.5	23	42	0.23A (1.92A)	0.10 (0.83)
1.25	16	38	0.16A (1.33A)	0.09 (0.75)
1.00	14	37	0.14A (1.17A)	0.09 (0.75)
0.625	13	35	0.13A (1.08A)	0.08 (0.67)
TOTAL	100	100	1A (8.34A)	0.24 (2.00)

[a] Reference 29. Source Classification Codes: 1-03-004-01/02/03/04 and 1-03-005-01/02/03/04.
[b] Expressed as aerodynamic equivalent diameter.
[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content where S is the weight % of sulfur in the oil. For example, if the fuel is 1.0% sulfur, then S equals 1.0.
No. 6 oil: A = 1.12(S) + 0.37 kg/10^3 L,
No. 5 oil: A = 1.2 kg/10^3 L
No. 4 oil: A = 0.84 kg/10^3 L
No. 2 oil: A = 0.24 kg/10^3 L

particulate emissions from fuel oil combustion. Uncontrolled and controlled size-specific emission factors are presented in Figure 1.3-1, Figure 1.3-2, Figure 1.3-3, and Figure 1.3-4. Distillate and residual oil categories aregiven separately, because their combustion produces significantly different particulate, SO_2, and NO_x emissions.

1.3.2.1 Particulate Matter Emissions[3-7,12-13,21,23-24] -

Particulate matter emissions depend predominantly on the grade of fuel fired. Combustion of lighter distillate oils results in significantly lower PM formation than does combustion of heavier residual oils. Among residual oils, firing of Nos. 4 or 5 oils usually produces less PM than does the firing of heavier No. 6 oil.

In general, PM emissions depend on the completeness of combustion as well as on the oil ash content. The PM emitted by distillate oil-fired boilers is primarily carbonaceous particles resulting from incomplete combustion of oil and is not correlated to the ash or sulfur content of the oil. However, PM emissions from residual oil burning is related to the oil sulfur content. This is because low sulfur No. 6 oil, either refined from naturally low sulfur crude oil or desulfurized by one of

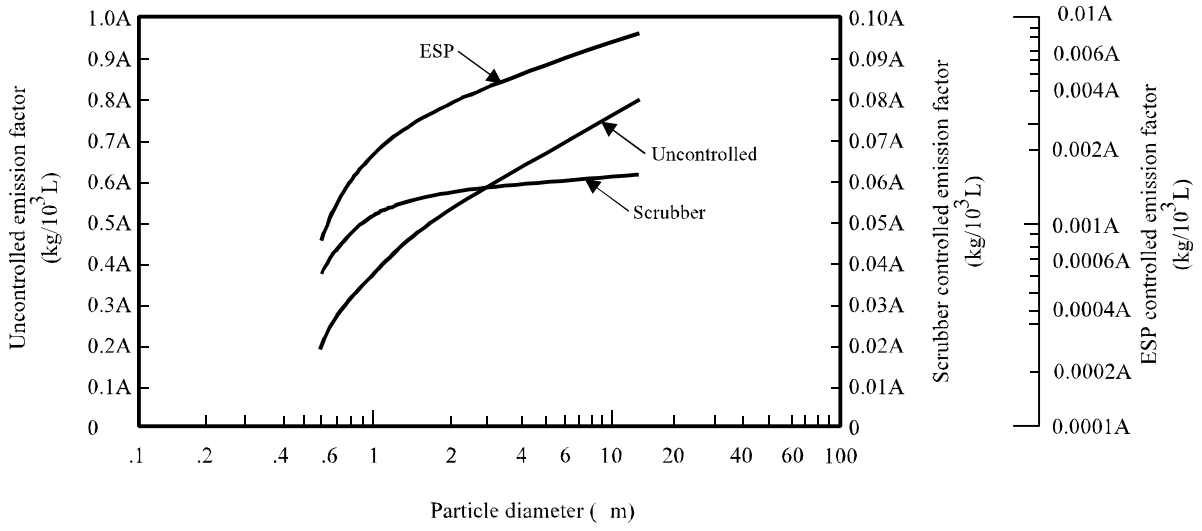

Figure 1.3-1. Cumulative size-specific emission factors for utility boilers firing residual oil.

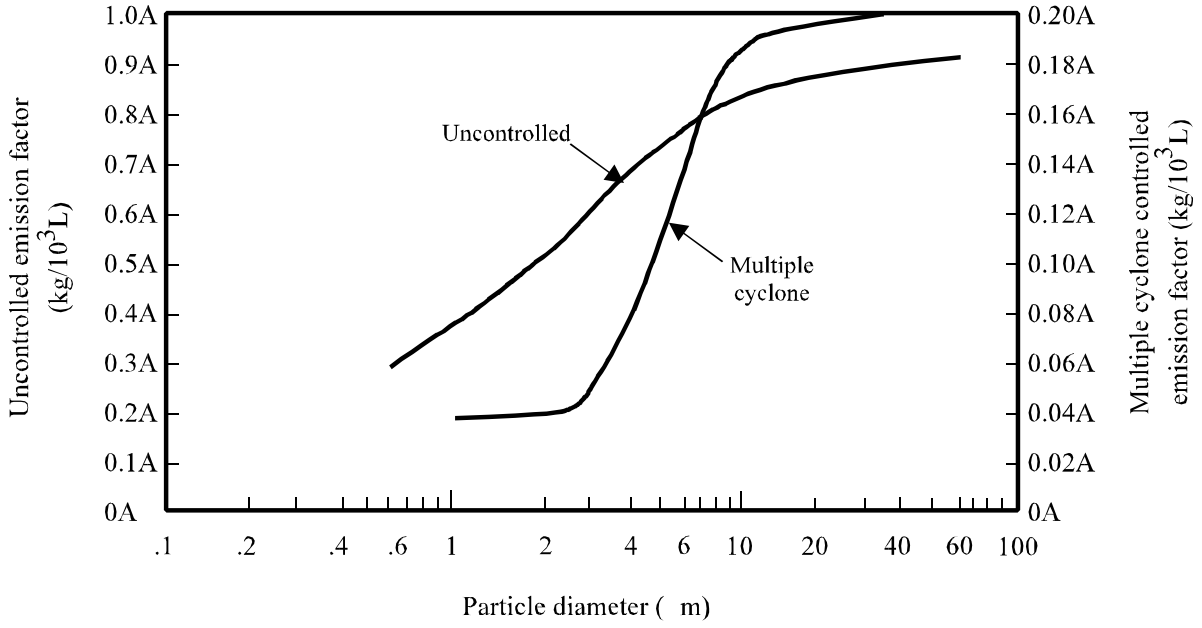

Figure 1.3-2. Cumulative size-specific emission factors for industrial boilers firing residual oil.

combustion (SC), reduced air preheat (RAP), low NO_x burners (LNBs), or some combination thereof may result in NO_x reductions of 5 to 60 percent. Load reduction (LR) can likewise decrease NO_x production. Nitrogen oxides emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, influence the NO_x emissions only of large oil fired boilers. Low excess air-firing is possible in many small boilers, but the resulting NO_x reductions are less significant.

Recent N_2O emissions data indicate that direct N_2O emissions from oil combustion units are considerably below the measurements made prior to 1988. Nevertheless, the N_2O formation and reaction mechanisms are still not well understood or well characterized. Additional sampling and research is needed to fully characterize N_2O emissions and to understand the N_2O formation mechanism. Emissions can vary widely from unit to unit, or even from the same unit at different operating conditions. It has been shown in some cases that N_2O increases with decreasing boiler temperature. For this update, average emission factors based on reported test data have been developed for conventional oil combustion systems. These factors are presented in Table 1.3-9.

Table 1.3-9 (Metric And English Units). EMISSION FACTORS FOR NITROUS OXIDE (N_2O), POLYCYCLIC ORGANIC MATTER (POM), AND FORMALDEHYDE (HCOH) FROM FUEL OIL COMBUSTION

EMISSION FACTOR RATING: E

Firing Configuration (SCC)[a]	Emission Factor, kg/10^3 L (lb/10^3 gal)		
	N_2O[b]	POM[c]	HCOH[c]
Utility/industrial/commercial boilers			
No. 6 oil fired (1-01-004-01, 1-02-004-01, 1-03-004-01)	0.013 (0.11)	0.00013-0.00015 (0.0011-0.0013)	0.0029-0.0073 (0.024-0.061)
Distillate oil fired (1-01-005-01, 1-02-005-01, 1-03-005-01)	0.013 (0.11)	0.00040 (0.0033)	0.0042-0.0073 (0.035-0.061)
Residential furnaces (No SCC)	0.006 (0.05)	ND	ND

[a] SCC = Source Classification Code. ND = no data.
[b] References 28-29.
[c] References 16-19.
[d] Particulate and gaseous POM.
[e] Particulate POM only.

The new source performance standards (NSPS) for PM, SO_2, and NO_x emissions from residual oil combustion in fossil fuel-fired boilers are shown in Table 1.3-10.

1.3.2.4 Carbon Monoxide Emissions[16-19] -

The rate of CO emissions from combustion sources depends on the oxidation efficiency of the fuel. By controlling the combustion process carefully, CO emissions can be minimized. Thus if a unit is operated improperly or not well maintained, the resulting concentrations of CO (as well as organic compounds) may increase by several orders of magnitude. Smaller boilers, heaters, and furnaces tend to emit more of these pollutants than larger combustors. This is because smaller units

Table 1.3-10 (Metric And English Units). NEW SOURCE PERFORMANCE STANDARDS FOR FOSSIL FUEL FIRED BOILERS

Standard/ Boiler Types/ Applicability Criteria	Boiler Size MW (Million Btu/hr)	Fuel Or Boiler Type	PM ng/J (lb/MMBtu) [% reduction]	SO_2 ng/J (lb/MMBtu) [% reduction]	NO_x ng/J (lb/MMBtu) [% reduction]
Subpart D	>73 (>250)	Gas	43 (0.10)	NA[d]	86 (0.20)
Industrial-Utility		Oil	43 (0.10)	340 (0.80)	129 (0.30)
Commence construction after 8/17/71		Bit./Subbit. Coal	43 (0.10)	520 (1.20)	300 (0.70)
Subpart Da	>73 (>250)	Gas	13 (0.03) [NA]	340 (0.80) [90][a]	86 (0.20) [25]
Utility					
Commence construction after 9/18/78		Oil	13 (0.03) [70]	340 (0.80) [90][a]	130 (0.30) [30]
		Bit./Subbit. Coal	13 (0.03) [99]	520 (1.20) [90][a]	260/210[c] (0.60/0.50) [65/65]
Subpart Db	>29 (>100)	Gas	NA[d]	NA[d]	43[f] (0.10)
Industrial-Commercial Institution		Distillate Oil	43 (0.10)	340[n] (0.80) [90]	43[f] (0.10)
Commence construction after 6/19/84[m]		Residual Oil	(Same as for distillate oil)	(Same as for distillate oil)	130[g] (0.30)
		Pulverized Bit./Subbit. Coal	22[e] (0.05)	520[e] (1.20) [90]	300 (0.70)
		Spreader Stoker & FBC	22[e] (0.05)	520[e] (1.20) [90]	260 (0.60)
		Mass-Feed Stoker	22[e] (0.05)	520[e] (1.20) [90]	210 (0.50)

Table 1.3-10 (cont.).

Standard/ Boiler Types/ Applicability Criteria	Boiler Size MW (Million Btu/hr)	Fuel Or Boiler Type	PM ng/J (lb/MMBtu) [% reduction]	SO_2 ng/J (lb/MMBtu) [% reduction]	NO_x ng/J (lb/MMBtu) [% reduction]
Subpart Dc	2.9 - 29 (10 - 100)	Gas	—[h]	—	—
Small Industrial Commercial-Institutional		Oil	—[h,j]	215 (0.50)	—
Commence construction after 6/9/89		Bit./Subbit. Coal	22[j,k] (0.05)	520[k] (1.20) [90]	—

[a] Zero percent reduction when emissions are less than 86 ng/J (0.20 lb/MMBtu). FBC = fluidized bed combustion. NA = not applicable.
[b] 70 percent reduction when emissions are less than 260 ng/J (0.60 lb/MMBtu).
[c] The first number applies to bituminous coal and the second to subbituminous coal.
[d] Standard applies when gas is fired in combination with coal; see 40 CFR 60, Subpart Db.
[e] Standard is adjusted for fuel combinations and capacity factor limits; see 40 CFR 60, Subpart Db.
[f] For furnace heat release rates greater than 730,000 J/s-m^3 (70,000 Btu/hr-ft^3), the standard is 86 ng/J (0.20 lb/MMBtu).
[g] For furnace heat release rates greater than 730,000 J/s-m^3 (70,000 Btu/hr-ft^3), the standard is 170 ng/J (0.40 lb/MMBtu).
[h] Standard applies when gas or oil is fired in combination with coal; see 40 CFR 60, Subpart Dc.
[j] 20 percent capacity limit applies for heat input capacities of 8.7 Mwt (30 MMBtu/hr) or greater.
[k] Standard is adjusted for fuel combinations and capacity factor limits; see 40 CFR 60, Subpart Dc.
[m] Additional requirements apply to facilities which commenced construction, modification, or reconstruction after 6/19/84 but on or before 6/19/86 (see 40 Code of Federal Regulations Part 60, Subpart Db).
[n] 215 ng/J (0.50 lb/million Btu) limit (but no percent reduction requirement) applies if facilities combust only very low sulfur oil (<0.5 wt. % sulfur).

usually have a higher ratio of heat transfer surface area to flame volume leading to reduced flame temperature and combustion intensity and, therefore, lower combustion efficiency than larger combustors.

The presence of CO in the exhaust gases of combustion systems results principally from incomplete fuel combustion. Several conditions can lead to incomplete combustion, including:

- insufficient oxygen (O_2) availability;
- poor fuel/air mixing;
- cold wall flame quenching;
- reduced combustion temperature;

- decreased combustion gas residence time; and

- load reduction (i. e., reduced combustion intensity).

Since various combustion modifications for NO_x reduction can produce one or more of the above conditions, the possibility of increased CO emissions is a concern for environmental, energy efficiency, and operational reasons.

1.3.2.5 Organic Compound Emissions[16-19,30-35,64] -

Small amounts of organic compounds are emitted from combustion. As with CO emissions, the rate at which organic compounds are emitted depends, to some extent, on the combustion efficiency of the boiler. Therefore, any combustion modification which reduces the combustion efficiency will most likely increase the concentrations of organic compounds in the flue gases.

Total organic compounds (TOCs) include VOCs, semi-volatile organic compounds, and condensible organic compounds. Emissions of VOCs are primarily characterized by the criteria pollutant class of unburned vapor phase hydrocarbons. Unburned hydrocarbon emissions can include essentially all vapor phase organic compounds emitted from a combustion source. These are primarily emissions of aliphatic, oxygenated, and low molecular weight aromatic compounds which exist in the vapor phase at flue gas temperatures. These emissions include all alkanes, alkenes, aldehydes, carboxylic acids, and substituted benzenes (e. g., benzene, toluene, xylene, and ethyl benzene).

The remaining organic emissions are composed largely of compounds emitted from combustion sources in a condensed phase. These compounds can almost exclusively be classed into a group known as polycyclic organic matter (POM), and a subset of compounds called polynuclear aromatic hydrocarbons (PNA or PAH). There are also PAH-nitrogen analogs. Information available in the literature on POM compounds generally pertains to these PAH groups.

Formaldehyde is formed and emitted during combustion of hydrocarbon-based fuels including coal and oil. Formaldehyde is present in the vapor phase of the flue gas. Formaldehyde is subject to oxidation and decomposition at the high temperatures encountered during combustion. Thus, larger units with efficient combustion (resulting from closely regulated air-fuel ratios, uniformly high combustion chamber temperatures, and relatively long gas retention times) have lower formaldehyde emission rates than do smaller, less efficient combustion units. Average emission factors for POM and formaldehyde from fuel oil combustors are presented in Table 1.3-9, together with N_2O emissions data.

1.3.2.6 Trace Element Emissions[16-19,36-40] -

Trace elements are also emitted from the combustion of oil. For this update of AP-42, trace metals included in the list of 189 hazardous air pollutants under Title III of the 1990 Clean Air Act Amendments are considered. The quantity of trace metals emitted depends on combustion temperature, fuel feed mechanism, and the composition of the fuel. The temperature determines the degree of volatilization of specific compounds contained in the fuel. The fuel feed mechanism affects the separation of emissions into bottom ash and fly ash.

The quantity of any given metal emitted, in general, depends on:

- the physical and chemical properties of the element itself;

- its concentration in the fuel;